

An Efficient PMG based Wind Energy Conversion System with Power Quality Improvement Features

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Abstract— This paper presents an efficient small scale wind energy conversion system using permanent magnet generators (PMGs) and power electronic converters. In the proposed system, variable magnitude and variable frequency of PMG are converted to constant DC using a full bridge rectifier and closed loop boost converter. This constant DC output is converted to AC using Grid interfacing inverter. The inverter is controlled in such a manner that it can perform as a conventional inverter as well as an active power filter. The inverter can thus be utilized as a power converter injecting power generated from renewable energy source to the grid and as a shunt active power filter to compensate for power quality disturbances and load reactive power demand.

Index Terms— Active Power Filter (APF), Closed loop DC-DC Boost Converter, Grid Interfacing Inverter, Hysteresis Control; PMG, Power Quality

I. INTRODUCTION

The generation of electricity from modern wind turbines is now an established technology. Among AC type generation systems, those based on PMG is one of the most favorable and reliable methods of power generation for small and large wind turbines. To meet the amplitude and frequency requirements of conventional loads, the amplitude and frequency outputs of PMG require additional conditioning. This paper presents an efficient small scale wind energy conversion system using PMG and power electronic converters. In the proposed system, the PMG output is converted to constant DC using full bridge rectifier and closed loop boost converter. This constant DC output is converted to AC using Grid interfacing inverter. The inverter uses hysteresis control to function as an active power filter. The inverter can thus be utilized as a power converter injecting power generated from renewable energy sources to the grid. It also serves as a shunt active power filter to compensate the power quality disturbances such as load current harmonics and load reactive power demand.

II. SYSTEM DESCRIPTION

A block diagram of the proposed system is shown in Fig. 1. The wind turbine is the prime mover of the PMG. As wind velocity is non-uniform, the output of the PMG would be fluctuating in nature. Therefore it cannot be directly interfaced to the grid. The output of the PMG is converted to constant DC using a full bridge rectifier and a closed loop boost

converter. This constant DC output is converted to AC using Grid interfacing inverter. The inverter was controlled using hysteresis controller so that it worked as a conventional grid interfacing inverter with active power filter functionality.

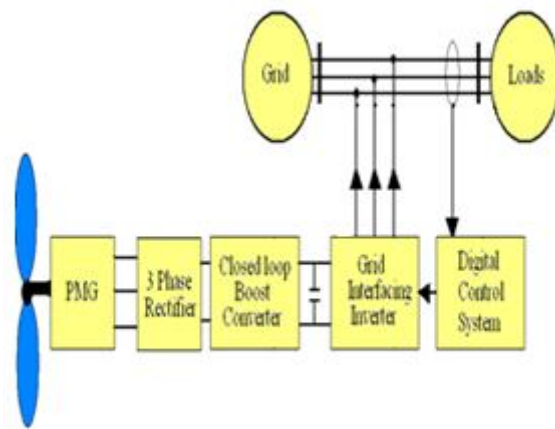


Figure 1. Block diagram of the proposed system

A. Permanent Magnet Generator (PMG)

This paper focuses on Permanent Magnet (PM) machine as a generator for the wind turbine system. Such machines may be grouped in several categories; those with surface mounted magnets, those with buried magnets, and those with damper windings [1]. PM machines with surface mounted magnets can be designed with relatively large air-gap. Such machines have a relatively large air-gap, leading to leakage flux falling below an acceptable limit. PM machines with a large number of poles may be designed with smaller D/L value for a given output. This eases the mechanical problems encountered when building and operating a large generator. Surface mounted magnets also eliminate the problems of high voltages at high speeds. Advantages of PMGs are high power density, lower rotor inertia and low acoustic noise [2], [3].

B. Rectification and Regulation

The 3 phase full bridge diode rectifier converts 3 phase AC generated by PMG to DC. Magnitude of DC varies with change in AC input. The varying DC output of the three phase rectifier is maintained constant with the help of a closed loop DC-DC converter. Closed loop boost converter steps up variable DC to constant DC [6]. In the proposed system, a PI controller based closed loop boost converter is used. Its output remains constant even if there are variations in the input voltage. Closed loop control is obtained by comparing

the reference signal (measure of the desired output voltage) with the output of the boost converter. The duty ratio of the boost converter is adjusted to compensate the changes in the input voltage, thereby keeping the output voltage at a desired value [4], [5].

C. Grid Interfacing and Power Quality Improvement

One of the most common problems when connecting small renewable energy systems to the electric grid concerns the interface unit between the power sources and the grid, as it can inject harmonic components that may deteriorate the power quality. Fig. 2 shows the schematic diagram of the proposed system.

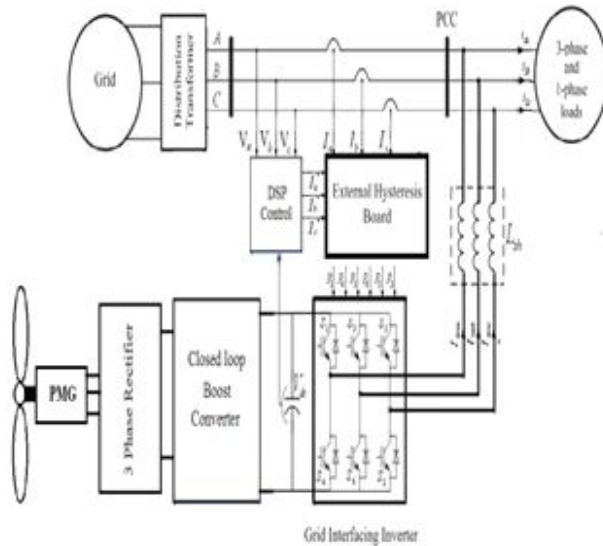


Figure 2. Schematic diagram of the proposed system

The fluctuating output from the PMG can be converted to constant DC using a full bridge rectifier and a closed loop boost converter. The inverter coupled to it can convert this DC to AC and it is fed to the grid. This inverter is controlled by using a digital control system. By sensing the actual grid voltages and the dc link voltage, the control system can generate reference grid current signals. These signals are compared with the actual grid current values and the error is given to a hysteresis controller. The hysteresis controller output would be the switching pulses for the IGBTs of the inverter.

This system could incorporate the features of APF in the conventional interfacing inverter. It was sought to utilize the inverter fully which was otherwise underutilized due to the intermittent nature of renewable energy sources. The grid-interfacing inverter could perform the following chief functions: 1) To transfer the active power harvested from the renewable resources; 2) To support the load reactive power demand; 3) And to compensate harmonics. Moreover, with adequate control of the grid-interfacing inverter, all the objectives could be accomplished either individually or simultaneously. The PQ constraints at the PCC could therefore be strictly maintained within the utility standards without additional hardware cost [6].

III. CONTROL SYSTEM

The control system of the proposed one included the control of the closed loop boost converter and the grid side inverter. The boost converter is controlled to maintain a constant DC input to the grid interfacing inverter. The grid interfacing inverter control system could provide active and reactive power injection and harmonic compensation, and thereby power quality is improved.

A. Control Strategy for Boost Converter

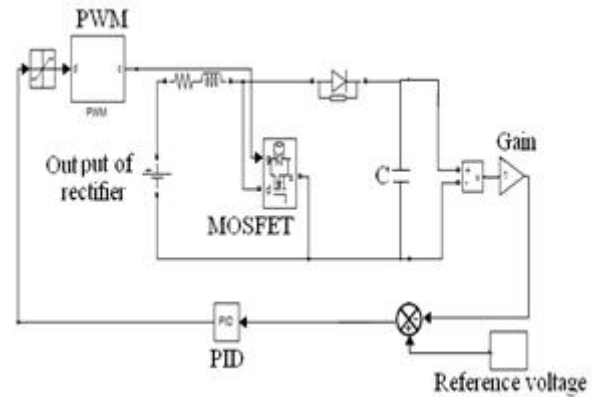


Figure 3. Control strategy for closed loop DC-DC boost converter
Control strategy for closed loop DC-DC boost converter is shown in Fig.3. Here output voltage is sensed and is compared with a set reference voltage. The error is processed through a PID controller whose output is used to modulate the pulses that drive the MOSFET gate. Gate signals of MOSFET are generated by PWM by comparing a carrier signal with the signal generated by PID controller. The simplest way to generate a PWM signal will be the interceptive method, and that required only a saw tooth or a triangular waveform and a comparator [7]. When the value of the reference signal is more than the modulation waveform, the PWM signal would be in the high state lest it would be in the low state.

B. Control Strategy for Grid Side Inverter

Control strategy for grid side inverter is shown in Fig. 4. The duty ratio of inverter switches are varied in a power cycle.

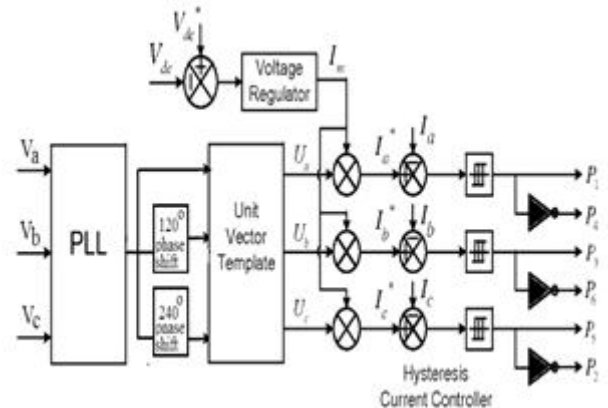


Figure 4. Control strategy for grid side inverter

The DC-link voltage can carry the information regarding the exchange of active power in between PMG and grid. Thus the output of DC-link voltage regulator will result in active current. The multiplication of active current component with unity grid voltage vector templates (U_a , U_b and U_c) would generate the reference grid currents (I_a^* , I_b^* and I_c^*). The grid synchronizing angle obtained from phase locked loop (PLL) is used to generate unity vector template,

$$U_a = \sin\theta \quad (1)$$

$$U_b = \sin(\theta - 2\pi/3) \quad (2)$$

$$U_c = \sin(\theta + 2\pi/3) \quad (3)$$

The actual DC-link voltage is sensed and consequently compared with the reference DC-link voltage. The difference of this DC-link voltage (V_{dc}) and reference DC-link voltage (V_{dc}^*) is given to a discrete-PI regulator to maintain a constant DC-link voltage. The output of the discrete-PI regulator is I_m . The instantaneous values of the reference three phase grid currents could be computed as,

$$I_a^* = I_m \cdot U_a \quad (4)$$

$$I_b^* = I_m \cdot U_b \quad (5)$$

$$I_c^* = I_m \cdot U_c \quad (6)$$

The reference grid currents (I_a^* , I_b^* and I_c^*) were compared with actual grid currents (I_a , I_b and I_c) to compute the current errors which were given to the hysteresis current controller. The hysteresis controller then generated the switching pulses (P_1 to P_6) for the gate terminals of grid-interfacing inverter.

IV. SIMULATION RESULTS

In order to check the performance of the proposed system, an extensive simulation study was done by using MATLAB7.1. The system was tested with different load and source voltages and the voltage was measured at different points in the simulation circuit. The designed system generated AC power with an AC source (36V; 50Hz) instead of PMG. This variable frequency, variable magnitude three-phase AC was converted to DC by using a three phase rectifier. The rectifier output is shown in Fig. 5.

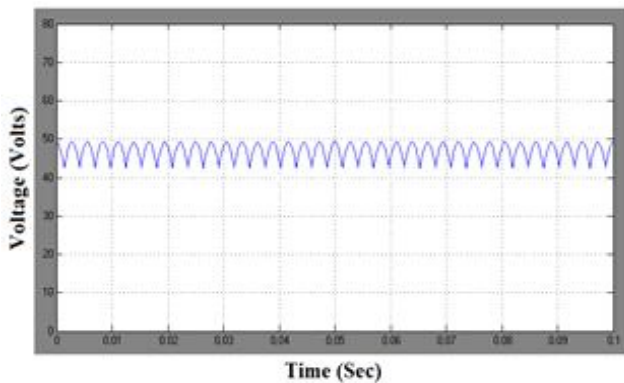


Figure 5. Output voltage of three phase rectifier

This DC voltage was then boosted with a closed loop boost converter (CLBC) which used PWM technique to regulate the DC voltage. Output of the closed loop boost converter is shown in Fig. 6. This output would invariably be constant. This DC voltage was then converted to three phase AC using grid interfacing inverter.

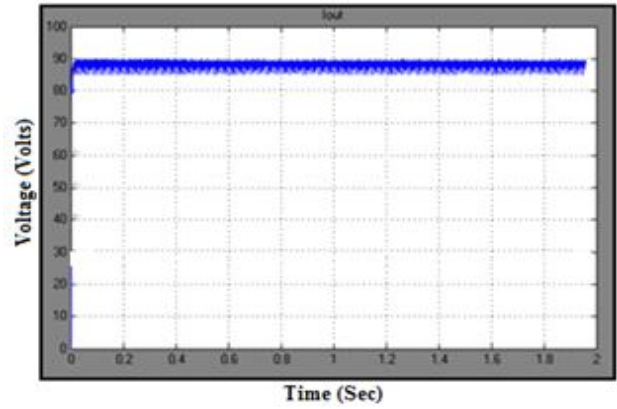


Figure 6. Output voltage of closed loop boost converter

A Three-leg inverter was actively controlled to achieve sinusoidal grid currents despite highly unbalanced non-linear load. The regulated output of the source was connected to the dc link of grid interfacing inverter. Initially the grid interfacing inverter was not connected to the network. The waveforms of grid voltages, grid currents, load voltages, load currents and inverter currents are shown in Fig. 7. At this time the grid current profile was identical to the load current profile. Fig. 8 shows the waveforms of grid voltages, grid currents, load voltages, load currents and inverter currents, when inverter was connected to the system. When the inverter was connected to the grid, it injected active power generated from the source. Since the generated power was more than the load power demand, the additional power was fed back to the grid. The grid interfacing inverter also supplied the load reactive power demand locally. Thus when inverter was in operation the grid only supplied/received fundamental active power.

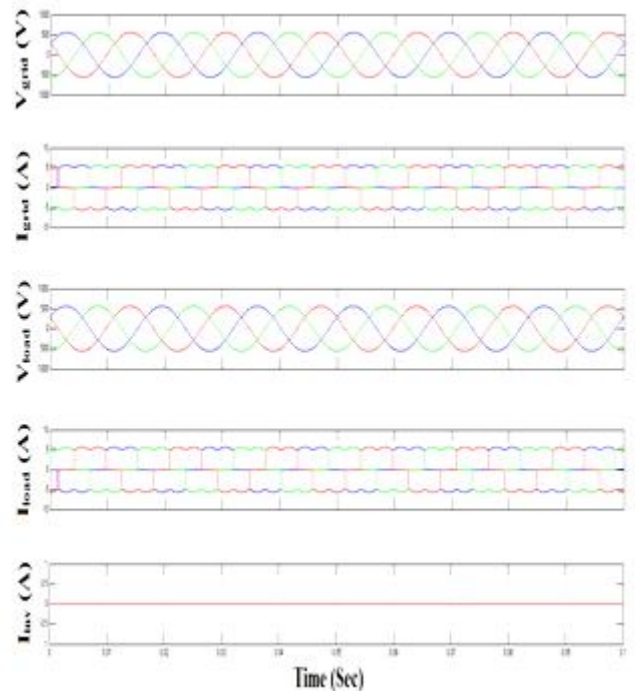


Figure 7. Simulation results: As the inverter is not connected to the system

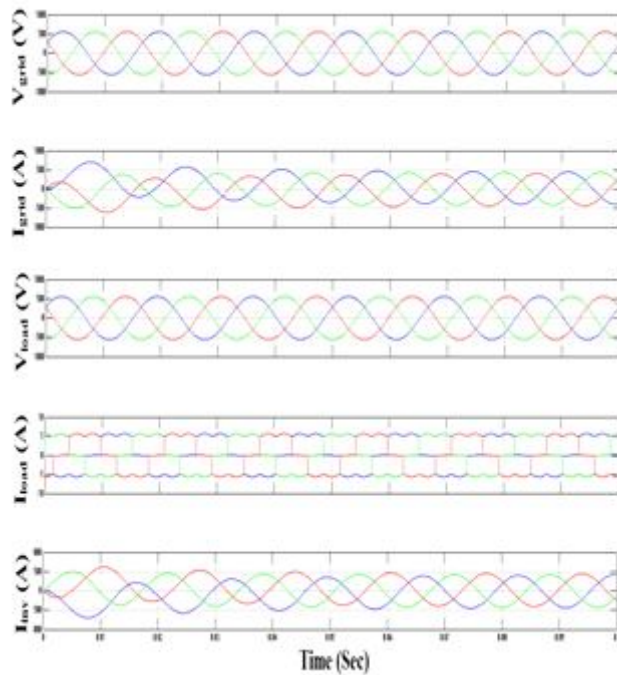


Figure 8. Simulation results: As the inverter is connected to the system

CONCLUSIONS

This paper presents an efficient control method for PMG based wind energy conversion system. In the proposed system, the output of the PMG is converted to constant DC using a full bridge rectifier and a closed loop boost converter. This constant DC output is converted to AC using a grid interfacing inverter. By suitable control of grid interfacing inverter, it could function as shunt active filter for compensating the power quality disturbances present in the system and thereby power quality of the system could be improved. The proposed system is designed in such a manner that it could incorporate the features of APF in the conventional inverter interfacing renewable energy sources

with the grid, without any additional hardware cost. Extensive simulation study was done by using MATLAB/Simulink to validate the proposed approach. The simulation results demonstrated that the output of the boost converter remained constant even though the output of the PMG was fluctuating. And also the grid interfacing inverter was controlled in such a manner that the power quality issues such as current unbalance, current harmonics and load reactive power due to unbalanced and non-linear loads were effectively compensated and the grid side currents were maintained as balanced and sinusoidal.

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